Cellular Bucket Brigades

A Self-Balancing Scheme for U-Shaped Production Lines

Yun Fong LIM

yflim@smu.edu.sg

Lee Kong Chian School of Business
Singapore Management University

SMU
SINGAPORE MANAGEMENT UNIVERSITY

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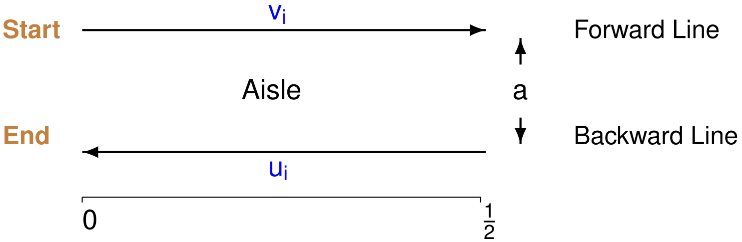
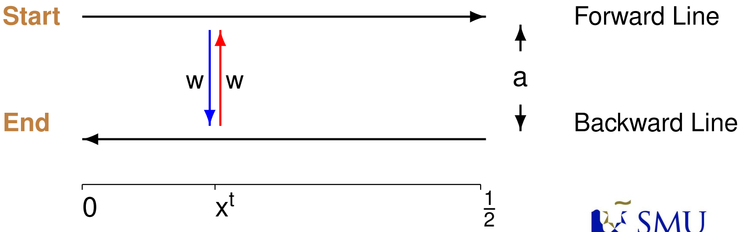
A **cellular bucket brigade** is a way to coordinate workers in a production line where work content is distributed on both sides of an aisle.

Consider a production line as follows. Each worker i works with a speed v_i in the forward direction, and works with a speed u_i in the backward direction.



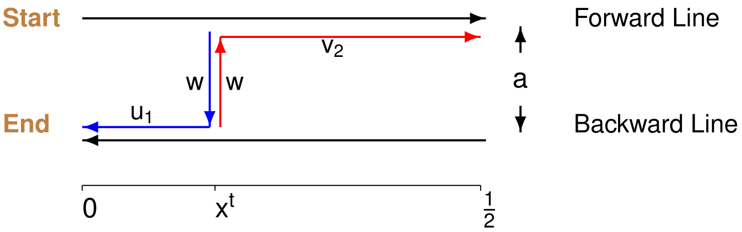
Hand-off

Instead of completing a job individually, workers transfer their work through 'hand-offs'. For a two-worker system, a **hand-off** occurs when worker 1 moving forward meets worker 2, who is moving backward, along the aisle (point x^t along the aisle). The workers exchange their work in the hand-off by crossing the aisle with a speed w.



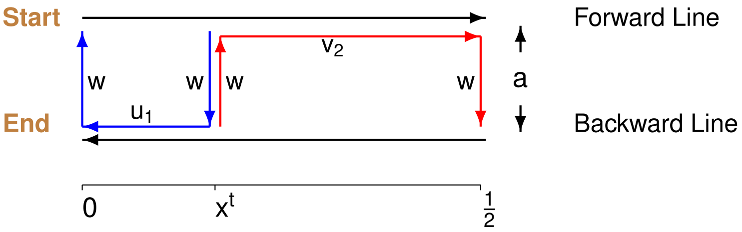
After the hand-off ...

After the hand-off, worker 1 (blue) works backward with a speed u_1 and worker 2 (red) works forward with a speed v_2.



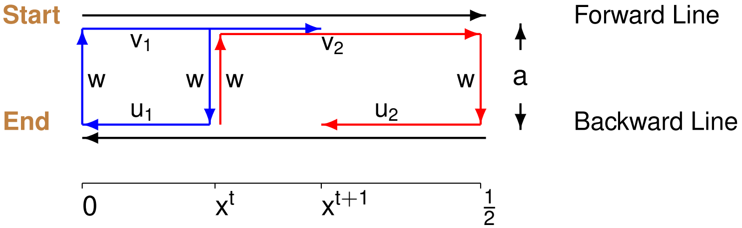
When they reach the ends ...

When the workers reach the ends, they make a U-turn by crossing the aisle again.



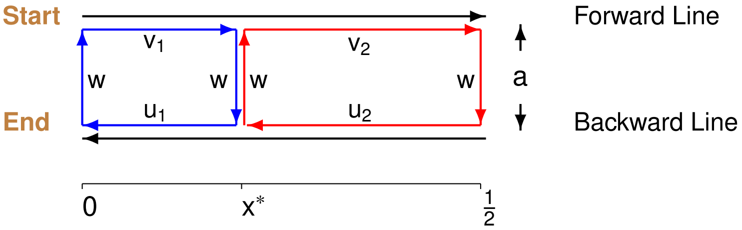
After the U-turn ...

After the U-turn, worker 1 (blue) works forward with a speed v_1 and worker 2 (red) works backward with a speed u_2. The workers meet again at point x^{t+1} along the aisle.



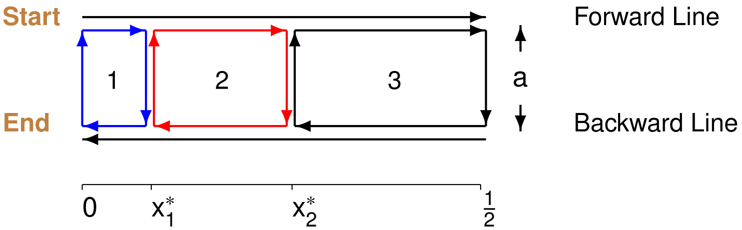
Self-balance of cellular bucket brigades

If the hand-off location $x^t \to x^*$ as $t \to \infty$, then each worker will eventually work in a loop or a 'cell'. We say the system **self-balances**.



Self-balance of cellular bucket brigades

Here is an example of a three-worker system in the balance.



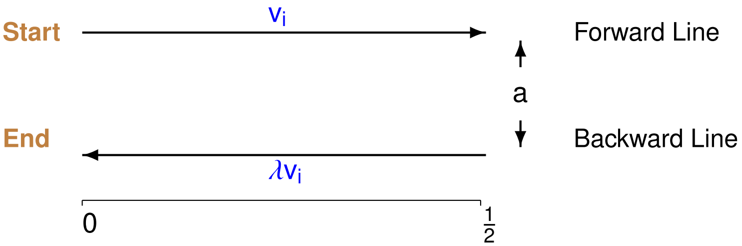
Theorem:

A cellular bucket brigade self-balances if

$$\frac{1}{v_1} - \frac{1}{u_1} > \frac{1}{v_2} - \frac{1}{u_2} > \cdots > \frac{1}{v_n} - \frac{1}{u_n}.$$

Lim YF (2011) Cellular bucket brigades. *Operations Research*, **59**(6), 1539-1545.

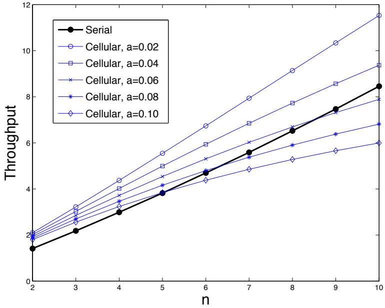
Consider a **special case** where each worker i works with a speed v_i in the forward direction, and works with a speed λv_i in the backward direction.

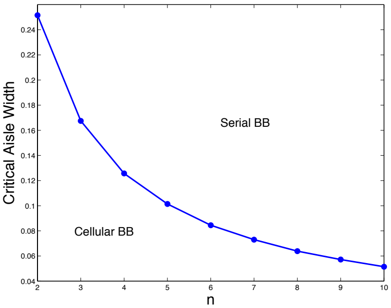


- If $\lambda > 1$ then workers should be sequenced such that $v_1 < v_2 < \ldots < v_n$.
  If forward line has more work, then sequence the workers from slowest to fastest in the forward direction.
- If $\lambda < 1$ then workers should be sequenced such that $v_1 > v_2 > \ldots > v_n$.
  If backward line has more work, then sequence the workers from slowest to fastest in the backward direction.

Cellular vs serial bucket brigades

Given the same team of workers, a cellular bucket brigade is **more productive** than a serial bucket brigade if the team size *n* and the aisle width *a* are small.





Lim YF (2011) Cellular bucket brigades. *Operations Research*, **59**(6), 1539-1545.

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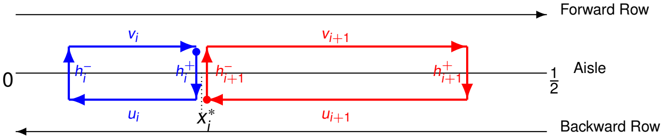
The same idea can be applied to a situation where each worker i spends times h_i^- and h_i^+ in a hand-off with his predecessor (worker $i-1$) and successor (worker $i+1$) respectively.



Lim YF (2017) Performance of cellular bucket brigades with hand-off times. *Production and Operations Management*, **26**(10), 1915-1923.

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The idea can also be applied to **warehouse order-picking** where each worker can pick products from both sides of an aisle.

Lim YF (2012) Order-picking by cellular bucket brigades: A case study.
In *Warehousing in The Global Supply Chain*, ed. R. Manzini, Springer-Verlag London, 71-85.

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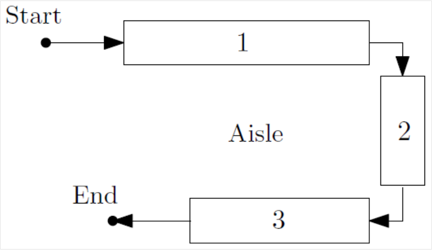
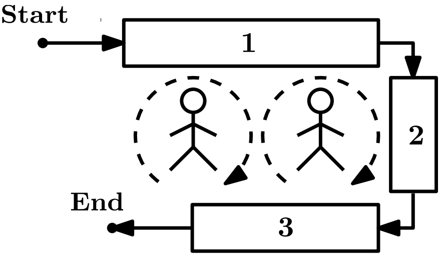
Applying the ideas on U-lines

U-line with discrete work stations



Dynamic U-line balancing



Assumptions:

1. Only one worker can work on a station at any time
2. Worker *i* works on stage *j* with velocity v_{ij}
3. Instantaneous walk

Lim YF, Wu Y (2014) Cellular bucket brigades on U-lines with discrete work stations. *Production and Operations Management*, **23**(7), 1113-1128.

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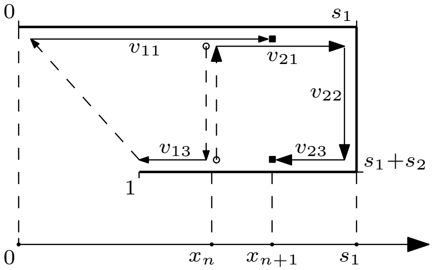
Cellular bucket brigade rules on a U-line



Worker 1:

- Assemble a new item on Station 1 until you meet your colleague.
- Assemble your item on Station 3 until you finish.

Worker 2:

- Assemble your item along the line until you meet your colleague.

References

- Lim YF (2011) Cellular bucket brigades. *Operations Research*, **59**(6), 1539-1545.
  - https://ink.library.smu.edu.sg/lkcsb_research/3202/
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- Lim YF, Wu Y (2014) Cellular bucket brigades on U-lines with discrete work stations. *Production and Operations Management*, **23**(7), 1113-1128.
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